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13. ABSTRACT *(Maximum 200 words)*
The purpose of this study is to investigate secular change in body dimensions (height, weight, %body fat (%BF)) in U.S. Army female soldiers, by comparing the 2004 and 1988 databases. Identified anthropometric somatotypes were subsequently incorporated in a thermal regulatory model to examine simulated individual differences in core temperature (Tcr) to heat stress (rest for 30 min and walk @ 3mph with 12 kg load in 35° C/50%rh environment for 70 min). The results were also compared to those from the male study. The univariate results indicated that the secular trend, greater increases in weight (3.1kg) and %BF (1.8%) ($p < 0.05$, after Bonferroni correction) than men were observed in the 2004 database. Multivariate results demonstrated that five primary somatotypes ("tall-fat," "tall-thin," "average," "short-thin," "short-fat") were identified. Despite the increase in "fatness," the secular trend of female body composition in multivariate dimensions and its effects on Tcr were not significantly different between the 1988 and 2004 databases. Anthropometric values in each somatotype differed by gender but surprisingly affected minimal gender differences in predicated Tcr to heat stress simulations..

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ASSESSMENT OF ANTHROPOMETRIC TRENDS AND THE EFFECTS ON THERMAL REGULATORY MODELS: FEMALES VERSUS MALES

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INTRODUCTION

In a previous study, 15-year trends in body size and composition of U.S. Army male Soldiers were characterized. The predicted effects of the anthropometric changes on the physiological responses to work in a hot environment were examined using a thermal regulatory model (5). Body weight increased significantly, but not height or percent body fat (%BF). Temporal changes in the five primary somatotypes, which were identified by multivariate analysis, had no significant effect on the simulated thermo-physiological responses. Similarly, this study examined temporal changes in body dimensions of U.S. Army female Soldiers and evaluated the anthropometric effects on core temperatures (T_{cr}) during a simulated thermal challenge.

METHODS

Height, weight, and %BF of female volunteers with self-reported race/ethnicity from the 2004 database (n = 904) were compared with those from the 1988 database (n = 2206) (1,3). The %BF was estimated using a U.S. Department of Defense % BF equation (2). Anthropometric distributions in two databases were compared using analysis of variance and principal component analysis (PCA). The multivariate distribution using PCA was identified with a 90% ellipse representing the majority of the two populations. Identified anthropometric variables on the ellipses were utilized in a thermal regulatory model to examine physiological differences to simulated heat stress (5). The model simulated non-acclimatized individuals wearing battle dress uniform (BDU) and body armor and carrying a 12 kg load, who rested for 30 min and then walked at 3 mph for 70 min in 35ºC and 50% relative humidity (rh) conditions. The time needed to reach a T_{cr} of 38.5ºC, representing the point where the probability of heat illness was 25% (6), was utilized as the key threshold of heat strain.

RESULTS

A summary of the female Soldier characteristics and inter-observer measurement errors (4) for the 1988 and 2004 databases are summarized in Table 1. The modest temporal increase in height (0.5 cm) was insignificant, being less than the inter-observer error (Table 1). The increases in weight (3.4 kg) and BMI (1.2 kg/m^2) between the 1988 and 2004 databases were significant and greater than that observed in the previous male study (7). In contrast to the small change in %BF observed in males (7), a significant temporal increase in female %BF (1.8%) was observed from 1998 to the 2004. The increase in %BF resulted from increases in abdominal (3 cm), hip (1.7cm) and neck (0.9cm) circumferences. The two 90% ellipses in Figure 1 represent the 1988 and 2004 populations. Overall, these results are similar to those shown in the male study (7). In addition, similar anthropometric distributions between the 1988 and 2004 populations were observed. The first component (X axis), explains 65% of the total variation, corresponds to all positive loadings of variables indicating overall size (Figure 1). The second component (Y axis), explains 33% of the total variation, is associated with the dichotomous height and %BF loadings representing somatotypes such as “tall-lean” vs. “short-fat”. The third component was eliminated due to its representing only 2% of the total variation in this study. The labels in Figure 1 summarize the main somatotypes and their anthropometric values converted from PCA scores in each population. For instance, “A^{88}” in Figure 1 corresponds to a “tall-fat” somatotype (height: 172 cm, weight: 84kg, BF%: 39%)

from the 1988 population. Anthropometric values for each somatotype applied to a thermal regulatory model resulted into physiological response comparisons of Figure 2 and 3.

Table 1. Descriptive summary of female anthropometrics and tolerance values of inter-observer errors based on 1988 and 2004 populations

Anthropometric variables	Database		Inter-observer error range
	1988	2004	
n	2206	904	
Age (yr)	27 (7)	27 (8)	N/A
Height (cm)	163.1 (6.3)	163.6 (6.1)	1.1
Weight (kg)	62.4 (8.6)	65.8 (10.6)*	0.3
Body Mass Index	23.5 (2.7)	24.6 (3.4)*	N/A
Body fat (%)	28.2 (5.3)	30.0 (6.7)*	N/A
Body surface (m^2)	1.67 (0.13)	1.71 (0.14)*	N/A
Neck circumference (cm)	31.6 (1.5)	32.5 (1.9)*	0.6
Waist circumference (cm)	72.9 (6.5)	76.1 (8.7)*	1.1
Hip circumference (cm)	97.1 (6.2)	98.8 (7.9)*	N/A

N/A: not available; Anthropometric values: mean (standard deviation).
*statistical difference between 1988 and 2004 database at $p < 0.05$ after Bonferroni correction (8 measurements)

Figure 2 shows T_{cr} comparisons between somatotypes in the 2004 population. Overall, female Soldiers, depending upon somatotype, can perform their tasks for up to 91 min in the simulated hot environment. “Short-lean” individuals, were predicted to be more tolerant of heat stress and were able to maintain their T_{cr} efficiently in heat. On the other hand, “fat” individuals, whether short or tall, were predicted to experience greater heat strain. However, overall, within each somatotype, differences in physiological responses were minimal between the 1988 and 2004 datasets.

Figure 3 shows the example of T_{cr} comparisons between “tall-fat” males (MA) and females (FA) from the 1988 and 2004 databases. Although primary somatotype categories are the same in females and males, the anthropometric values corresponding to each somatotype differ by gender. Within the same somatotype, males are generally taller and heavier than females although females have higher %BF than males. Under the heat stress simulation, the gender differences in T_{cr} were overall less pronounced. The differences in heat tolerance time for 1988 and 2004 databases were 1 and 5 min, respectively (Figure 3). The trend of greater differences in heat tolerance time in the 2004 database than the 1988 database, resulted from the female “tall-fat” somatotype being heavier and fatter in the 2004 database.

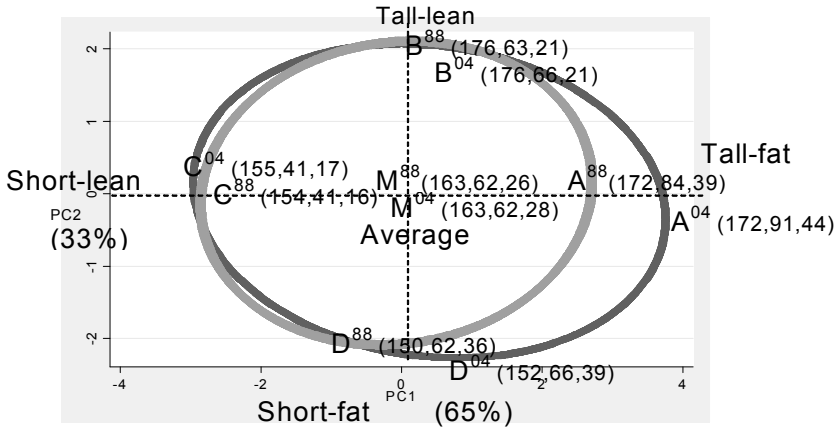

Figure 1. A two-dimensional plot for the 1988 and 2004 databases of female Soldiers with 90% ellipses. (Height: cm, Weight: kg, Body fat: %) values converted from principal component scores

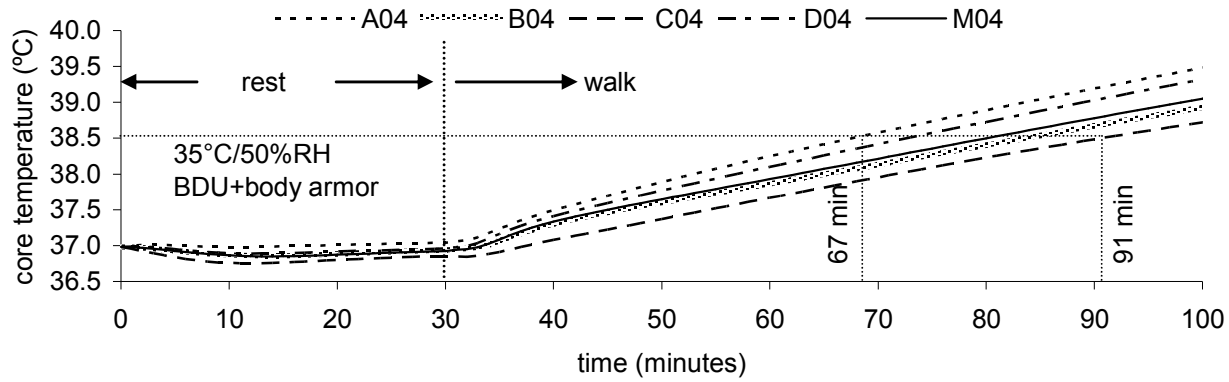

Figure 2. Anthropometric effects on core temperatures by female somatotypes. A^{04}:"tall-fat", B^{04}: "tall-lean", $C0^{4}$: "short-lean", D^{04}: "short-fat", M^{04}: "average" somatotypes

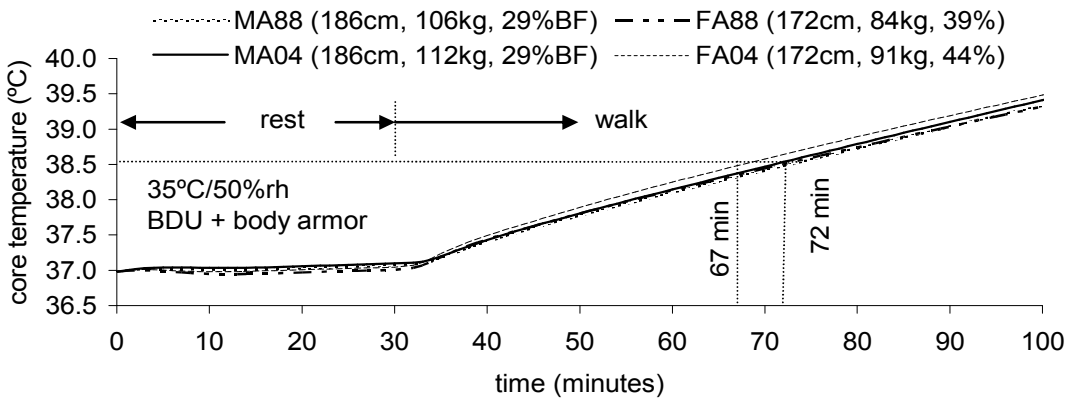

Figure 3. Gender comparisons in core temperature between the 1988 and 2004 "tall-fat" somatotypes

DISCUSSION

While the major temporal increase was weight in males (7), weight and %BF were major increases in the U.S. Army female populations over the past 15 years. Five identified

somatotypes in multivariate anthropometric distributions showed different heat tolerance levels: lean people were able to lower their T_{cr} than fat people in the heat simulation conducted in this study. However, the differences in each somatotype between 1988 and 2004 had a minimal effect on simulated T_{cr} in a heat stress. Although the same somatotypes were identified in males and females, body measurements in the somatotypes differed by gender. The gender differences in heat strains were not prominent in all somatotypes in this study. However, the trend of the gender differences in the "tall-fat" somatotype were slightly greater in the 2004 than 1988 database, due to the increase in fatness among 2004 female populations. If the trend in fatness keeps increasing in females, "tall-fat" groups of the female population will be more likely to experience heat strains and thermal injuries, and less able to work as long as other somatotypes in the heat, unless proper acclimatization and training to thermal stresses are provided.

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DISCLAIMER

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